



DESIGN CONCEPTS FOR THE BEAM SCRAPER SYSTEM
OF THE MAIN RING

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The beam scraper system can be divided into three component systems.

1. Extraction clean-up system: Beam scattered from the extraction septum should be cleaned up.

2. & 3. Horizontal and vertical scraping systems: These are used to clean up the beam before extraction.

Extraction Clean-Up System

The first septum (electrostatic) of the present slow extraction system as designed by Maschke is placed at 3 cm from the central orbit. The step-over of the beam at the septum due to excitation of the $1/3$ integral resonance by sextupole magnets is $1/3$ cm/turn (or 1 cm per 3 turns). With a horizontal beam emittance of 0.23π mm-mrad and $\beta \approx 100$ m at the septum the horizontal phase-space diagram during extraction looks roughly to scale like that shown in Figure 1. The divergence $\Delta x'$ of the beam at the septum (point B) depends on the rate of extraction, but is, in all cases, extremely small. For example, if the beam is spilled out uniformly over 200 msec, the phase-space area of the beam spilled out in 20 μ sec (one revolution) is

$$\frac{20}{2 \times 10^5} \times 0.23\pi \text{ mm-mrad} = 0.23 \times 10^{-4} \pi \text{ mm-mrad.}$$



Since the step-over per turn is 3.3 mm we have a theoretical value of $\Delta x' = \frac{4 \times 0.23 \times 10^{-4}}{3.3} = 0.28 \times 10^{-4}$ mrad. In practice the divergence will be larger because of misalignments, field errors and ripples, etc. Nevertheless, the divergence may be considered negligible.

Nuclear and multiple Coulomb scattering will impart a large (comparatively) divergence to the beam hitting the septum. This is indicated by the vertical line segment ABA' in Figure 1. The beam scattered outward (AB) will be extracted whereas the beam scattered inward (BA') will continue around the accelerator. After the phase diagram has rotated 300° (phase advance of the horizontal betatron oscillation), it looks like that shown in dotted line in Figure 1. A stopper TE placed at $\overline{OC} = (3 \text{ cm}) \cos 60^\circ = 1.5 \text{ cm}$ outward from the central orbit will "absorb" the scattered beam ($\overline{BA'}$). Since a stopper placed at 1.5 cm from the central orbit would limit the aperture during the entire accelerator cycle, the stopper should be moved out to 3.0 cm and the central orbit should be bumped outward 1.5 cm at TE by a pair of bump magnets. The physical beam and the location of the septum, stopper, and bump magnets are shown in Figure 2.

We now discuss the various components of this system.

1. Physical locations in the main ring lattice

The medium straight-section was, by design, located at 300° from the septum. Therefore, TE should be placed in the medium straight-section AM. The bump magnets will, then, have to be placed in the 7-ft short straight-sections

(ministraights). Since the phase advance per cell is about $360^\circ/5$, the two bump magnets should be $2\frac{1}{2}$ cells apart. The upstream bump magnet M1 should be placed in the second short straight-section upstream from AM and the downstream bump magnet M2 should be placed in the third short straight-section downstream from AM as shown on the bottom of Figure 2. The position of the scraper TE in the medium straight-section is not critical, but since the phase advance in $2\frac{1}{2}$ cells is not exactly 180° it may be necessary to place an additional small third bump magnet in the medium straight-section.

2. Bump magnets

The design of the bump magnets could be similar to those for the beam abort system except in this case any rise time shorter than, say, 1 msec is acceptable. After reaching full field, the magnets should be held at full field for the duration of the beam spill (up to 1 sec) with a stability of better than 1%. For a bump amplitude of 1.5 cm and $\beta \approx 100$ m the deflection angle required is 0.15 mrad corresponding to $B\ell = 1$ kGm which is very modest. At extraction these magnets could be turned on at the same time the resonance exciting sextupoles are turned on.

3. Stopper TE

Let us assume that the electrostatic septum is made up of 1 mil ($=0.00254$ cm) diameter tungsten wires. For such a thin wire, nuclear interactions are negligible. Assuming

further that on the average a proton goes through 10 wires we get for the root-mean-square angle due to multiple Coulomb scattering at 200 BeV

$$\theta_{\text{rms}} = 7.5 \times 10^{-5} \sqrt{\frac{0.0254}{0.36}} = 0.020 \text{ mrad (}=OA' \text{ in Fig. 1)}$$

At the position of the stopper this corresponds to a horizontal width of $\delta = 0.17$ cm for the beam hitting the incident face of the stopper. The fraction of this part of beam which is not absorbed by the stopper (scattered out of the boundary layer of the stopper) is, then, $\frac{F}{0.17} = 5.8F$ where F is given in Table 1 of FN-195. For Be this is 0.64% and for Fe this is 0.75%. It was estimated by Maschke that no more than 1% of the total beam will be scattered by the septum. Therefore, for an iron stopper only less than $0.5\% \times 0.75\% = 3.8 \times 10^{-5}$ of the total beam will be scattered out and spray the immediate downstream ring magnets. This should be quite tolerable.

With iron the stopper should be about 1.5 m long and could have the same picture frame construction as the stoppers for the abort system. The thickness of the frame, however, does not have to be much more than a few cm. The same requirements on the flatness of the boundary layer surface and on the alignment sensitivity and stability as those for the stopper T1 of the abort system should also be applied here.

Horizontal Scraping System

The difference between the scraping system and the abort system is that for the scraping system the beam must be moved

onto the stopper very slowly. The width of the beam hitting the incident face of the stopper must be increased to obtain reasonable stopping efficiency. To do this, it is proposed that a scatterer S be used ahead of the stoppers to spread out the beam to be scraped. The layout of the beam, the scatterer, and the stoppers is shown in Figure 3. The horizontal phase-space diagram is shown in Figure 4.

The scatterer spreads out the beam which is then stopped by two stoppers placed at 30° and 330° phase advances downstream of the scatterer. The edges of the stoppers are placed $\Delta = 1$ mm further outward from the central orbit than the scatterer.

To understand the action of the system more clearly let us assume that the beam with horizontal half-width \overline{OC} is suddenly moved to the position as shown in Figure 4 and held there. The beam in the sector AECG is scattered by the scatterer shown as line EAG to fill the area AEBFCHDG. The beam in the upper shaded area EBF will be stopped by stopper T1 shown as line EF when projected back to the position of S, and the beam in the lower shaded area HDG will be stopped by stopper T2 shown as line GH when projected back to the position of S. The beam originally in AECG is, thus, depleted. After, say, 100 revolutions all the beam in the annulus between the circles with radii \overline{OA} and \overline{OC} will be depleted to a negligible level and the beam half-width is reduced from \overline{OC} to \overline{OA} . Almost all the beam in the annulus is stopped by the stoppers because of the high stopper efficiency resulting from

large widths (\overline{BJ} and \overline{DK}) of the beams hitting the incident faces of the stoppers. It is now clear that the beam (rather, the fuzzy edge of the beam) will be efficiently scraped when it is moved in the $+x$ direction onto the scatterer-stopper system provided that the motion is sufficiently slow, say, of the order of 1 mm in 100 revolutions and that the final position of the beam is held for a sufficiently long time, say, again 100 revolutions.

We will now discuss the various components of this system.

1. Motion of the beam

The beam can be moved onto the system for scraping using either the main-ring RF system or a set of bump magnets. If the RF system is used, the scatterer and the stoppers should be located on the inner radius and the beam shrunk onto the system so as to avoid interference with the extraction septum located on the outer radius.

In the beam-bump scheme the bump magnets M1 and M2 should be located $1\frac{1}{2}$ oscillations apart as shown in Figure 3. In this case the beam could be bumped either inward or outward with the scatterer-stoppers placed on the corresponding side. The scheme of moving the beam by RF is clearly preferred.

2. Physical locations in the main ring lattice

The scraping system can be accommodated in a long straight-section and the immediately following medium

straight-section. The phase advance between the missing B1 at the beginning of a long straight-section (space provided for the extraction septum) and the medium straight-section has been designed to be 300° . These are then the appropriate locations for the stoppers T1 and T2. The 7-ft short straight-section (ministraight) immediately upstream from T1 is about 36° ahead. The proper location for S which should be 30° ahead of T1 falls, therefore, between two bending magnets. Since the scatterer is a simple piece of thin tungsten sheet, it can certainly be mounted in between bending magnets or even inside a bending magnet. In any case, both the 300° separation between T1 and T2 and the 30° separation between S and T1 can be adjusted slightly without degrading the performance.

If bump magnets are used it is likely that two magnets placed in neighboring short straight-sections are required for each bump magnet M1 or M2 to simulate its required proper location. The amplitude of the bump is no more than 4.5 cm. This requires only very modest magnets with $B\ell \leq 3$ kGm.

Since no component of the horizontal scraping system is located in the central drift space of the long straight-section, we can install this system in superperiod E sharing EL with the beam abort system.

3. Scatterer S

For an effective scatterer the divergence of the

scattered beam should be larger than the divergence of the original beam. At 200 BeV the beam emittance is 0.23π mm-mrad which gives a beam half-divergence for

$$\beta = 100 \text{ m of } \sqrt{\frac{0.23}{100}} = 0.048 \text{ mrad.}$$

For a "round" design parameter we will set the scatterer thickness equal to L_{rad} (3.6 mm for W). This gives $\theta_{\text{rms}} = 0.075$ mrad and a width of beam hitting the incident face of the stopper (Figure 4)

$$\Delta x = \overline{BJ} = \overline{DK} \cong (0.075 \text{ mrad}) \times (100 \text{ m}) \times \sin 30^\circ = 0.38 \text{ cm}$$

By simple inspection of Figure 4 which is drawn roughly to scale we can make the following crude estimate. Since \overline{AB} or \overline{AD} corresponds to θ_{rms} , with each revolution the beam inside the sector AEFCHG is depleted to roughly 20%. Furthermore, sector AEFCHG has about 10% the area of the annulus. In 100 revolutions, therefore, on the average the whole annulus will have undergone 10 depletion processes. This will reduce the beam in the annulus by a factor of $(0.2)^{10} = 10^{-7}$ indicating that the beam remaining in the annulus is entirely negligible.

4. Stoppers T1 and T2

With $\Delta x = 0.38$ cm the fraction of beam scattered out of the boundary layer of the stopper is $\frac{F}{0.38} = 2.7 F$ with F given in Table 1 of FN-195. For Be this is 0.30%, and for Fe it is 0.35%. The stoppers could, therefore, be made of iron

1.5 m long, and have the same configuration as the stopper TE of the extraction clean-up system. Since we will never have to scrape more than 1% of the design-intensity beam, this gives a maximum fraction of 3.5×10^{-5} of the design-intensity beam not stopped by the stoppers and spraying the ring magnets immediately downstream of the scraping system. This again is quite tolerable.

Vertical Scraping System

The design concept of the vertical scraping system is the same as that of the horizontal system except that the vertical beam emittance is smaller, hence the parameters must be adjusted accordingly. In addition, the beam can be moved vertically only with bump magnets.

Since both the drift space for the extraction electrostatic septum in the long straight-section insertion and the medium straight-section are rather long, both the horizontal and the vertical scraping systems can be accommodated in the same superperiod provided that the beam is moved for horizontal scraping by the main ring RF system. In this case, the short straight-sections have to accommodate only the vertical bump magnets.

Presented here is only the design concept of the beam scraper system. A great deal of additional analytical and computer work is necessary for optimizing the parameters and to provide adequate details for engineering design of the system.

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FIGURE 1

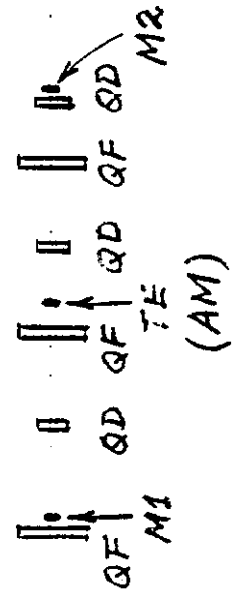
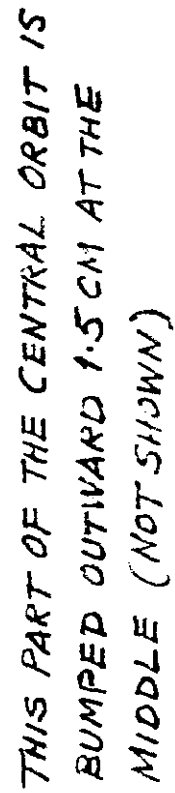
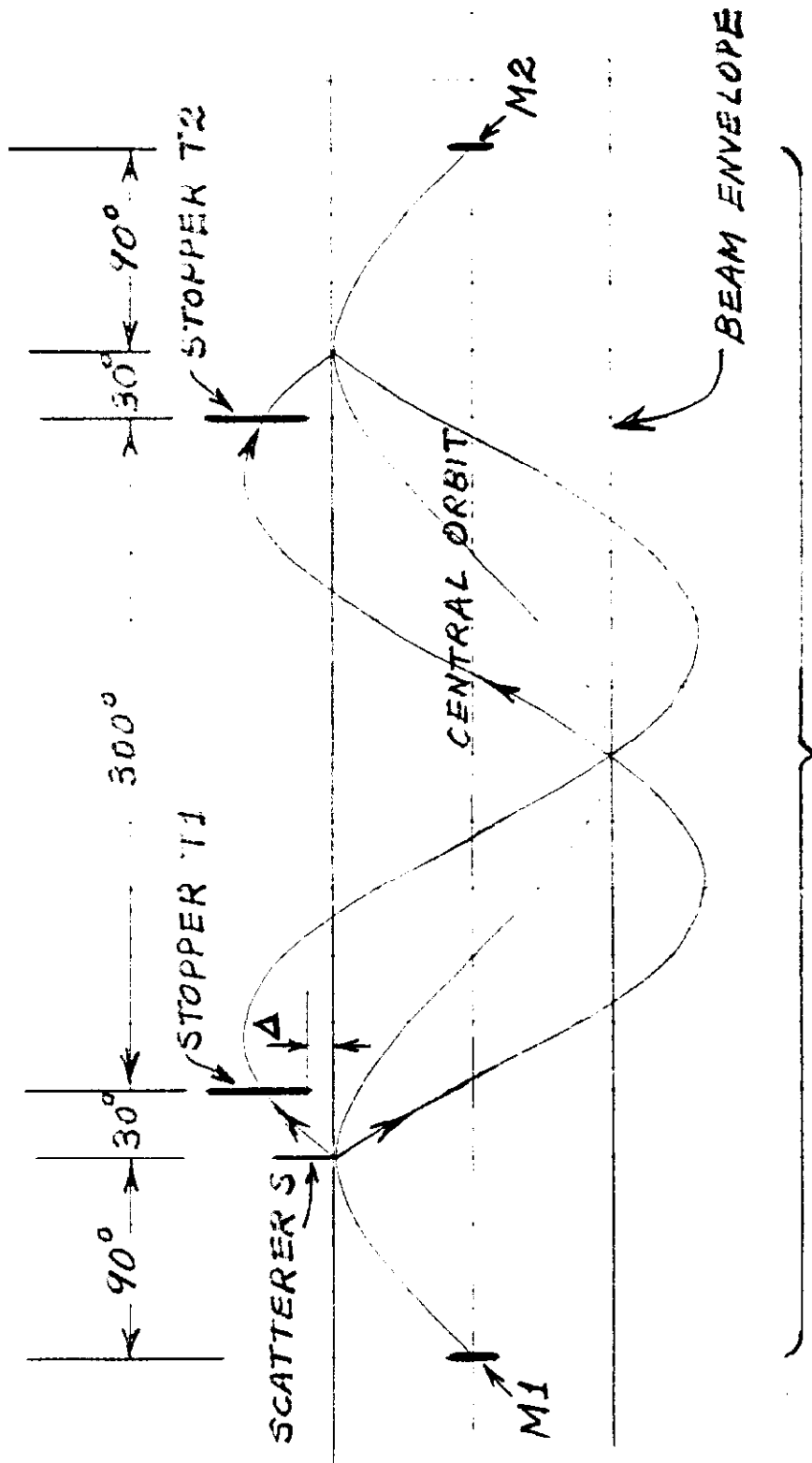


FIGURE 2



THIS PART OF THE CENTRAL ORBIT WILL BE BUMPED
OUTWARD IF THE BEAM-BUMPING SCHEME USING
BUMP MAGNETS M1 AND M2 IS ADOPTED

FIGURE 3

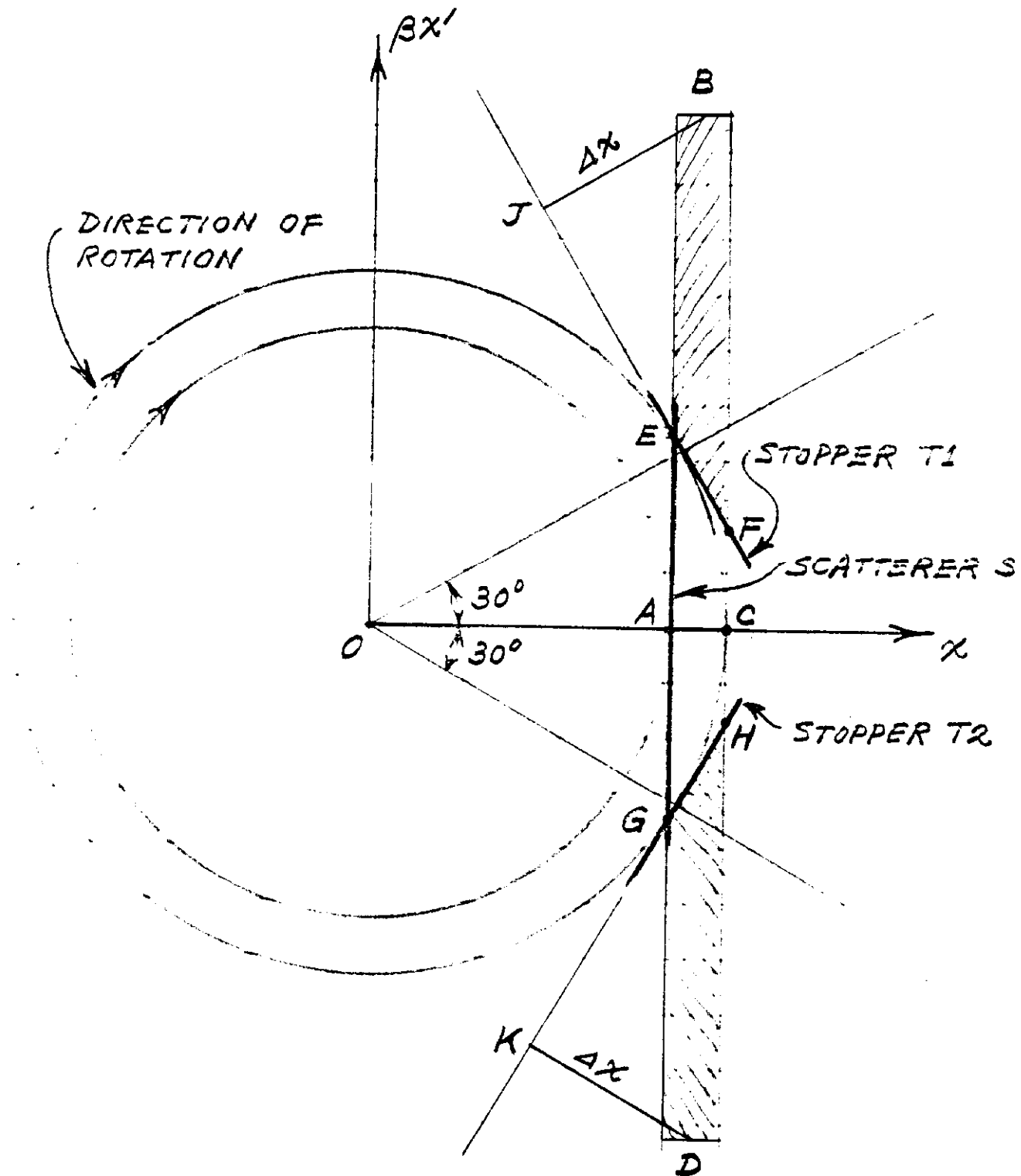


FIGURE 4